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The Effects of Drying Rate on Properties of Pigment Coated Papers

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THE EFFECTS OF DRYING RATE ON PROPERTIES OF PIGMENT COATED PAPERS

By:

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ABSTRACT

The objective of this study was to investigate the effects of drying rate on the characteristics of coated paper. A laboratory dryer was assembled consisting of an IR dryer and a steel backing can to dry the coated paper. Two differently sized papers and three drying rates were used. The final sheet properties increased as the rate of drying was increased from 0.27 to 0.49 lbs./hr.-ft.^{2}. Further increase in the drying rate had little effect on sheet properties. The surface of the coated paper was found to be more open after drying at the middle drying rate, thus giving the best optical and strength properties.

Keywords: Coating, Drying Rates, Coated Paper Properties, Binder Migration.

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INTRODUCTION

The purpose of this study is to investigate the effects of drying rate on coated paper properties. Past experience in the drying of coated paper has shown that the moisture in a coating color travels towards the outer surface, which is being heated by hot air, and towards the heated surface on a hot surface dryer. It has been suggested that slower removal of water may enable better surface bonds to form between the coating and the substrate, as well as within the coating. Therefore, this investigation explores the trends between the rate of drying and properties of coated paper.

ANALYSIS OF LITERATURE

The purpose of this work is to investigate the surface optical and strenght properties of coated paper dried at different rates. The coating that is applied to the paper is aqueous-based, containing dispersed pigment particles and dispersed and/or dissolved adhesives. The function of the coating is to improve the printing and appearance characteristics of the paper. Coatings serve to level the surface of the paper by filling in surface imperfections and pores. This improves the appearance of the final product, and its printability, smoothness, porosity, and gloss.

The function of the adhesive used in the coating formulation is to bond the pigment particles to the paper as well as to bond the coating to itself. Casey(1) stated that the adhesive exerts a profound influence on the properties of the coating mixture and the properties of the final coated paper. Adhesives used in pigmented coatings have two more functions in addition to the one stated above: to serve as a carrier for the pigment and to impart the required flow (rheological) behavior and water (and adhesive) retention to the coating mixture. Adhesives also serve to hold out printing ink vehicles to achieve high gloss surfaces.

The Base Stock

In order for the coating to do its job correctly, the base stock it is applied to first must have the proper characteristics. The base stock is one of the most important components involved in the coating process. This is because one cannot totally cover a badly made sheet. One of the most important properties of the base sheet is its sizing level because this greatly affects the rate of penetration of the coating into the sheet. Dappen (2) stated that the less the sheet was sized, the more the coating was keyed or bonded to the sheet. This would follow for the reason that more of the coating could flow into the sheet in a low-sized sheet. With more coating flowing into the sheet, the adhesive would have a greater chance to bond itself to the paper and to hold the coating more tightly to the sheet. On the other hand, too extensive liquid penetration into the base sheet may present a coated layer having low internal strength due to too low of a binder level as shown by Eames (3).

According to Hunger (4), the most important properties of the base sheet that need to be controlled are:

1. Uniformity
2. Formation
3. Finish
4. Sizing
5. Strength
6. Moisture Content
7. Porosity
8. Brightness
9. Opacity

Some factors of the base stock that Casey and Libby (5) found to affect penetration of starch from the coating into the base stock were:

1. Increasing density of the base stock reduced penetration;

2. Increasing the amount of size in the base stock reduced penetration with the greatest effects found in low density papers; and

3. Increasing moisture content increased penetration in unsized papers, with little or no effect on sized papers.

Eklund and Palsanen (6) found when working with wood-free papers that binder migration into the base sheet was increased when the time for capillary migration was increased or when total drying intensity decreased. They also came to the same conclusions as Dappen (2) and Casey and Libby (4) that high degrees of sizing reduce binder and coating migration into the paper.

Distribution of the Adhesive in the Coating

In an early study, Singleterry (7) showed that coatings keyed to the base stock by an intimate filling of the undercut regions about the surface fibers. The effectiveness of these keys in anchoring the coating depends upon the mechanical strength of the coating. When unkeyed portions of the coating separate from the sheet, a very thin film of coating remains attached to the sheet so that failure can be attributed to low mechanical strength of a zone in the coating itself and not failure of the coating to fiber interface. This zone is approximately one micron away from the coating/fiber interface, which is weaker than either the base stock or the main body of the coating (7).

Dappen (2) proposed that the mechanism of starch distribution involves primarily capillary competition for the vehicle between the base stock and the coating, but is also influenced by frying forces. Drying with a hot air blast on the coating side was found to increase the ratio of starch to clay.

Eames (3) suggested that the major loss of adhesive to the substrate occured in the saturated state of flow and that low rates of penetration of vehicle favored the maintenance of this type of flow, even to the extent that a greater volume of vehicle penetrated a substrate of small pore size than if did substrate of large pore size.

He found that coating strength was proportional to the binder concentration of the various layers of the coating which are a function of the rate and type of drying. The faster the coating was dried, the weaker it became. This is because of the binder was not allowed to migrate, but was set very quickly. In the drying of a coated sheet one needs a balance between the drying and penetration forces.

In later work, Heiser and Cullen (8) found that the prime factor governing the binder migration was the solids content of the coating formulation. The higher solids coatings were found to have less migration of the binder than coatings of low solids. The factor controlling which way the binder migrated were found to be the drying rate of the coating and the absorbency of the base stock. Heiser and Cullen also found that the degree of binder migration to the surface was proportional to the drying rate.

Johns (9) determined that stock binder migration could be minimized by reducing the air velocity of the dry and/or removing heat from the can backing the sheet in an air-cap dryer. The way Johns measured the degree of migration was by using an ink stain test. The areas in which migration appeared were areas of nonuniform ink absorption. The test was qualitatively evaluated by visual judging. The results of his work are in Table I.

TABLE I

Binder Migration Study of Starch Coating (9)

Nozzle Velocity, ft./min.		Level of Binder Migration
Low	Medium	
Aircap Dryer		
7,100	13,000	Extremely heavy
7,000	12,300	Heavy
6,500	10,700	Moderate
5,700	9,500	Slight
5,000	8,000	None
Airfoil Dryer		
6,800	10,100	None
6,200	9,500	None
5,700	8,800	None
5,000	8,000	None

Coating conditions: Speed = 1200 ft./min.; Coating Weight = 9 lb./ream; Coating Solids = 60%; Air Temp. = 600°F; Coating-Starch/PVAC Binder System.

Drying of Coated Paper

The removal of the liquid phase from the coating color applied to a sheet begins at the moment of application by liquid migration into the base stock. The remaining liquid will be removed in the drier section. The type, direction and rate of drying are important factors which have a profound influence on the dried coating properties.

In the drying process, three modes of heat transfer are recognized; viz. conduction, convection, and radiation. Radiation heat can be transferred without a medium in a form of electromagnetic wave motion, while convection uses fluid motion, such as air or water as the medium. Conduction involves transmission of heat through stationary solids, liquids, or gases.

Conduction and convection drying both occur during the drying cycle of a hot surface dryer. Air of low moisture content and high temperature directed torward the surface of the coating should be of sufficient velocity and quantity to penetrate the moisture vapor and air film immediately above the surface.

A hot surface dryer uses conduction predominantly because the heat transferred from the hot surface is the main driving force and source of energy for the removal of the moisture from the coated sheet. The rate of drying and drying capacity will be influenced by the temperature of the air supply, the moisture content of the air, and the intimate contact of the air with the coating surface.

Dreshfield (10) reported that water in a multi-ply assembly of paper sheets dried on a hot surface evaporated from the interior of the sheets into the air. The maximum moisture content was located 20 to 50% of the distance from the open to the hot surface. Liquid water, which was initially between this zone and the hot surface moved toward the hot surface; liquid water, which was between this zone and the cooler surface moved toward the cooler surface. The movement of liquid water was in a direction of decreasing moisture content and was predominantly toward the hot surface of the sheet. This phenomena showed that the water vaporized at the hot surface condensed, and gave up heat. This heat was then conducted to the water in zone of maximum moisture content for evaporation from the coller surface.

Sometime during the falling-rate period of drying, the driving force for the evaporation of water from the zone of maximum moisture content was heat conduction from the hot surface. This heat transfer continued until the multi-ply sheet was dry. It remains to be proven that thin paper contains dry by the above mechanism, but some of the observations may be significant.

The overall heat transfer coefficient in BUT/hr.-ft.^{2}-F^o can be calculated for the coatings by using a series of equations that Johns (9) developed in his study (see Appendix I for the equations).

Effects of Drying on Coated Paper Properties

Hultman (11) found that the first portion of drying is the most important in determining the final properties of the coated layer applied to the base sheet. This first portion of drying, was found to be of greater importance than the overall drying rate. The "critical time" or "set time" is the time that it takes for the coating to become immobile. This time occurs within the first few seconds after the coating is applied. In this time, the coating must be applied and the migration and drying forces of the system must be controlled exactly.

Figure 1 shows the set-up used by Hultman. The sheet was coated using a stationary rod. Entering the drying zone the coating could either be dried concurrently (I) or contercurrently (II). The backing can which the sheet traveled over in the dryer was temperature controlled by using five thermocouples in its shell.

Hultman (11) found that the final physical properties of the coated sheet were more a function of the drying conditions than of the coating formulations themselves. He found that the speed of the web, the direction

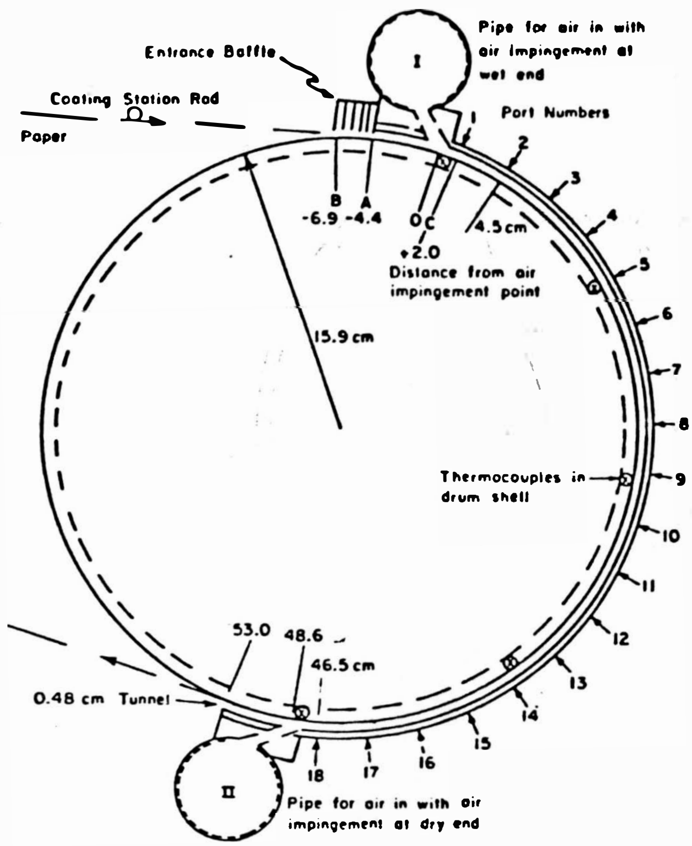


Figure 1. Schematic diagram of Hultman's Laboratory High Velocity Drier. (11)

and velocity of air flow were important. Also, the speed of the web was important because this determined the length of time the coating remained in the air impingement area. The direction of air flow is of great importance for the reason of sealing the surface of the coating and affecting the pick strength. The countercurrent air flow dried the coating in such a way as to leave it more open and of higher pick strength. Conversely, he found that in concurrent high velocity drying, the strength of the coating dropped sharply. This is because the surface is less likely to seal in countercurrent flow, for the reason that the high velocity air is not blowing right onto the surface and sealing the surface in the critical "set time". In countercurrent flow, the temperature of the sheet is raised evenly instead of all at once which will allow the sheet to dry evenly and control the migration of the binder.

Lee (12) found the various binders yielded gloss value losses in proportion to their film shrinkage. Thus, latexes shrank less than natural binders and gave higher gloss.

Summary of Literature

The above discussion has shown that the drying of coated paper has a powerful influence in controlling the final properties of the dried coating. Drying affects the way binder migrates, which in turn affects the final dried coating properties. In order to control the migration of the binder the drying of the coating should be done using countercurrent high velocity air flow system. The "set time" of the coating has been shown to be a more important factor in controlling binder migration than the rate of drying.

STATEMENT OF PROBLEM

The problem to be investigated in this study is the effect of drying rate on the characteristics of coated paper. The study will also look at the balancing of penetration and drying forces, using two differently sized based sheets. The main coating properties that will be studied are: opacity, brightness, porosity, smoothness, gloss, and pick strength. An ink wipe test will be used to observe coating mottle paterns. The reason the optical properties are being emphasized is that all the previous studies only looked at coating strength properties.

EXPERIMENTAL DESIGN

The objective of this study is to investigate the effects of drying rate on properties of pigment coated papers. The experimental work will include the coating of two differently sized papers. The coating will be done on a Keegan coater to an average coat weight of 10 lbs./ream.

The drying of the coating was going to be done using the Hultman design of Figure 1, but this experiment was unavailable, so the coating will be dried using an IR dryer at three different drying rates.

After the paper is coated it will be conditioned. Then, half of each coating run will be supercalendered and again conditioned. The following tests will be done to evaluate the effect of drying rate on final sheet properties:

1. Opacity
2. Brightness
3. Scattering Coefficient
4. Sheffield Porosity
5. ParkerPrint Surf Smoothness
6. Gloss
7. IGT Pick Strength
8. K & N Ink Absorption
9. An Ink Wipe Test to Test for Coating Mottle

EXPERIMENTAL MATERIALS AND PROCEDURES

Materials

In order to keep the base paper for this work as constant as possible the Western Michigan University pilot papermachine was used to make differently sized papers. The pulp used was bleached 50% Rayonier kraft softwood and 50% Weyerhaeuser kraft hardwood. This pulp was refined to 350 CSF using the pilot plant beater and Claflin refiner. The following chemicals were added to the pulp in the beater to adjust pH and calcium level; 250ml concentrated H_2SO_4 and 720g $CaCl_2$.

The two sizing levels were 0.3% and 0.5% Neuphor 100 (Hercules, Inc.) based on dry fiber. The pH of the first mix tank of the papermachine was adjusted to a pH of 6.2 using dilute H_2SO_4. The retention aid used in this work was alum at 12% solids at an addition level of 2% for a flow of 200 ml/min. The sizing agent was added on at 0.3% and 0.5% for a flow of 120 ml/min. and 200 ml/min. These flows are for a base sheet of 45 lbs./ream (25 x 38-500). After the paper was made it was taken to Impact Label of Kalamazoo, Michigan to be slit into rolls of 2000' in length and 7 3/8" in width, a size which fits the Keegan coater.

Clay Make-Up

1. A master batch of 75% solids clay was made, as follows;
2. 2300 g no. 1 clay was dispersed, in 766 g distilled water with 5.0 g Dispex (0.21% on dry fiber) using the laboratory Cowels mixer for 30 minutes.

Starch Make-Up

1. A master batch of 25% solids was used, made as follows;
2. 460 g of Penford Gum 280 was dispersed in 1380 g distilled water using a laboratory mixer, heated by steam and cooked at 190^{o}F for 30 minutes.

3. After the starch had cooled, dilution water was added to make up for evaporation during cooking.

Mixing of Coating

1. After the clay and starch were prepared, the starch was added slowly with mixing to the clay.

2. After the clay and starch were mixed well, 1000 g of distilled water was added, yielding a solids content of 44-46%.

3. The viscosity was then taken using a Brookfield Viscometer using the number five spindle at 100 rpm. The coating gave a viscosity of 300-500 cps.

The solids of the coating was checked by taking a sample to constant weight in an oven at 105^{o}F.

Procedures

The coating was applied to the sheet by using a roll applicator mounted on the Keegan coater. The coating was metered off the sheet using a stationary number 8 mayer rod. This gave a coat weight of approximately 10 lbs./ream. The coating was dried using the dyrer set-up shown in Figure 2. The dryer section consisted of an IR dryer of 0.33 feet of length mounted parallel to the sheet directly after the metering rod. Then the sheet was in contact with a backing can for 1.17 feet before going to the reel.

The drying conditions of each run were controlled by varying the voltage of the IR unit. To keep each run constant, the temperature throughout the dryer section was measured by an IR pyrometer. The tempratures were measured at each of the following locations (see Figure 2):

1. After the coating applications (TEMP 1),
2 After the IR unit (TEMP 2),
3. After the backing can (TEMP 3),
4. The temperature of the backing can (TEMP 4), and
5. The temperature of the air around the backing can (TEMP 5).

To calculate the water removal rate of the dryer section, the following measurements were taken:

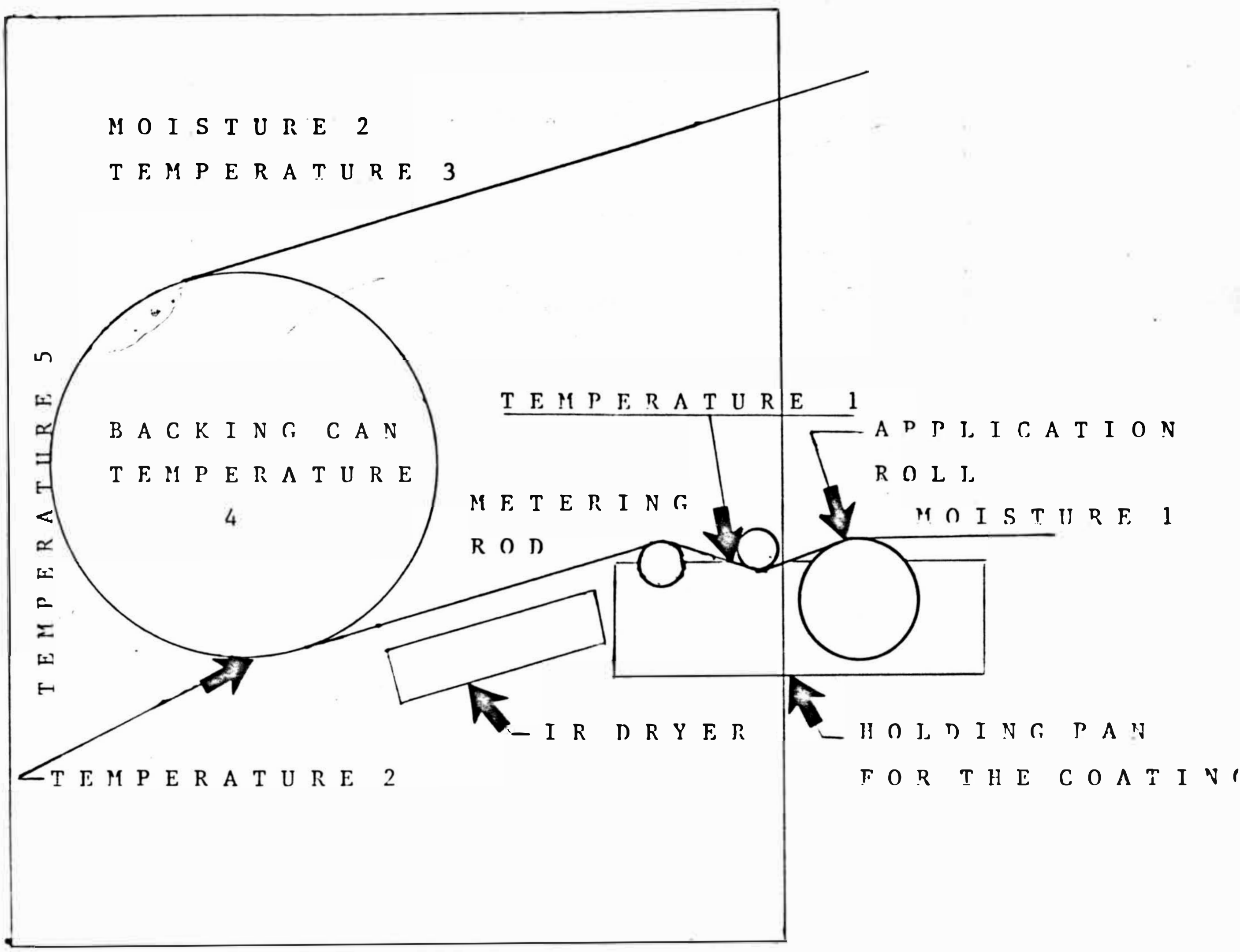


FIGURE TWO: DRYER SET-UP FOR EXPERIMENTAL WORK

1. The moisture of the base sheet (MOISTURE ONE),
2. The moisture leaving the backing can (MOISTURE TWO),
3. The base sheet basis weight, oven dry,
4. The base sheet basis weight, air dry,
5. The coated sheets basis weight, oven dry,
6. The percent solids of the coating, and
7. The speed of the coater.

The moisture of the base sheet, oven dry weight of the base sheet, and the oven dry weight of the coated sheets were determined by taking the sheets to constant weight in an oven at 105°C. The moisture was determined by subtracting the oven dry weight from the air dried weight. The speed of the coater was determined by placing a line on the backing can and timing how long it took to make ten revolutions. This was done four time during the run. The moisture of the sheet leaving the backing can was determined by using a bear claw to take a paper sample and placing this sample in a zip lock plastic bag. The samples moisture was then determined by weight difference after drying to constant weight in an oven at 105°C.

The water removal rate was calculated using the first five equations given by Johns (9), listed in Appendix I along with a sample calculation.

The coating conditions are summarized in the following tables: Table II gives a summary of the moistures, and temperatures shown in Figure 2 and the speed of the coater; Table III gives a summary of the basis weight data for the base sheets; and Table IV gives a summary of the coat weights and coating solids.

Supercalendering of the base papers and the coated papers was done on the W.M.U. laboratory supercalender. After the paper was coated and had conditioned for 24 hours at 50$\pm$ 2% and 73.0 $\pm$ 1.8°F, half the paper from each run was supercalendered using four nips at 40 psi. After supercalendering was completed, the papers were again allowed to condition for 24 hours.

TABLE TWO

SUMMARY OF DRYER CONDITIONS

SIZING LEVEL (%)	DRYING RATE lb./hr.-ft.^{2}	MOISTURE ONE (%)	MOISTURE TWO (%)	TEMP ONE °F	TEMP TWO °F	TEMP THREE °F	TEMP FOUR °F	TEMP FIVE °F	SPEED ft/min.
0.3	0.36	5.47	12.37	110	230	105	120	90	4.31
0.3	0.49	5.47	8.47	140	340	295	180	120	4.31
0.3	0.80	5.47	2.73	160	370	120	234	145	5.80
0.5	0.27	3.92	13.00	115	240	120	130	85	4.71
0.5	0.62	3.92	5.31	155	335	172	185	145	4.71
0.5	1.47	3.92	4.15	180	385	210	240	165	11.37

TABLE III

SUMMARY OF THE BASE PAPER BASIS WEIGHT DATA

SIZING LEVEL	lbs./ream (AD.)	lbs./ream (OD.)	% MOISTURE
0.3%	45.88	43.51	5.17
0.5%	44.94	43.18	3.92

TABLE IV

SUMMARY OF THE COATED STOCK BASIS WEIGHT DATA

SIZING (%)	DRYING CONDITIONS ($lbs./hr.-ft.^2$)	COAT WT (OD.) (lbs/ream)	BASIS WEIGHT (OD.) (lbs./ream)	COATING SOLIDS (%)
0.3	0.362	9.62	53.12	44.25
0.3	0.491	9.67	53.18	44.25
0.3	0.802	8.39	51.90	44.25
0.5	0.266	9.20	52.37	46.09
0.5	0.624	10.47	53.65	46.09
0.5	1.470	9.69	52.87	46.09

The testing of the paper properties were done following the following TAPPI Standards:

1.	Opacity	T 425
2.	Brightness	T 452
3.	Porosity (Sheffield)	UM 524
4.	Parker Print Surf Smoothness	*
5.	Gloss	T 480
6.	IGT Pick Strength	*
7.	K & N Ink Absorption	*
8.	Scattering Coefficient	*
9.	Hercules Sizing	*

*Appendix II gives the test procedure used for these tests.

Ten tests of each of the above properties were done on the calendered and uncalendered papers for each run and base paper.

Calculations were done using the Western Michigan University DEC-10 computer system. The main program package used was Statpack (13). The calculations included the means, standard deviations, and coefficient of variation. Tables V and VI give a summary of the means and standard deviations of the coatd paper properties.

Plots of the data appear in Figures 3-15 as the water removal rate versus the property in question.

TABLE V

SUMMARY OF COLLECTED DATA

DRYING RATE (lb/hr.-ft.^{2})	K&N INK (%)	OPACITY (%)	BRIGHTNESS (%)	POROSITY*	PRINT SURF** 10	PRINT SURF** 20	GLOSS (%)	SCATTERING COEFFICIENT	HERCULES SIZING (SECONDS)
0.3% SIZED BASE PAPER UNCALENDERED									
0.00	68.7	79.1	85.4	143.4	6.5	5.9	5.9	----	184.7
0.362	23.1	86.2	81.3	25.2	5.7	4.4	11.3	0.085	
0.491	20.1	87.1	81.0	18.1	5.7	4.5	12.3	0.098	
0.802	27.3	86.0	81.9	17.4	6.0	4.8	9.4	0.096	
0.3% SIZED BASE PAPER CALENDERED									IGT PICK STRENGTH (cm/s)
0.00	64.3	75.9	81.5	52.8	3.8	3.4	16.7	-----	------
0.362	11.6	83.3	78.4	5.6	1.7	1.3	45.6	0.0669	29.5
0.491	14.0	85.6	79.4	10.0	1.9	1.4	40.8	0.1037	29.8
0.802	17.2	83.9	79.7	6.0	2.1	1.7	36.1	0.0824	59.5
0.5% SIZED BASE PAPER UNCALENDERED									
0.00	69.3	77.0	84.7	298.6	7.1	6.4	7.0		222.7
0.226	24.4	85.6	81.2	25.4	5.8	4.7	11.4	0.1000	
0.624	21.8	87.7	80.9	18.1	5.9	4.7	12.8	0.1167	
1.470	24.2	87.3	81.5	18.1	6.0	4.9	10.6	0.1244	
0.5% SIZED BASE PAPER CALENDERED									IGT PICK STRENGTH (cm/s)
0.00	53.5	75.3	82.1	141.0	4.5	3.8	16.2	-----	----
0.226	12.4	80.1	77.5	5.3	2.4	2.1	49.4	0.0367	38.4
0.624	13.0	86.1	79.2	7.3	2.4	2.1	43.9	0.102	49.5
1.470	14.4	84.8	79.9	5.7	2.8	2.3	37.5	0.0943	48.8

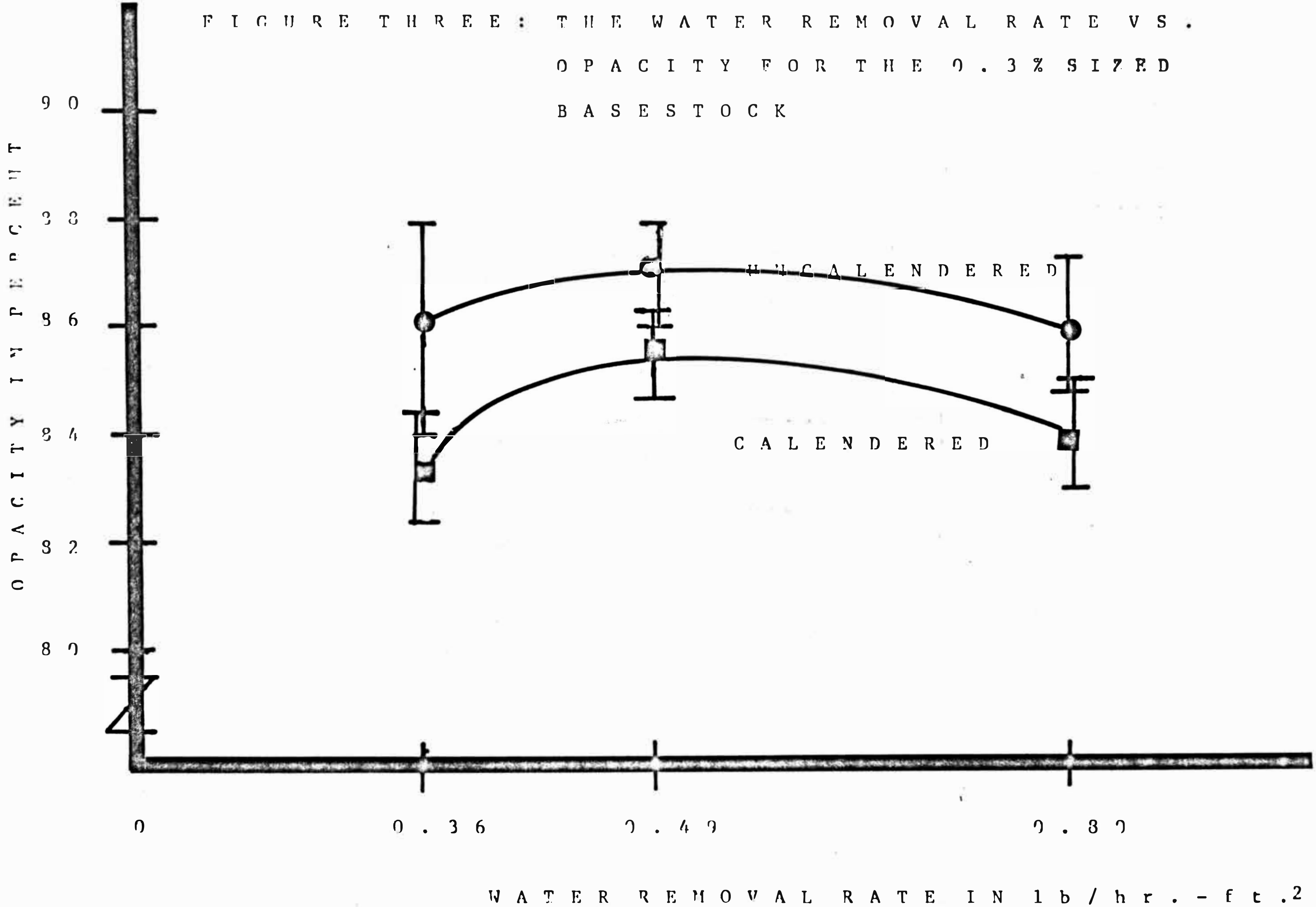
* Porosity is in Sheffield units ** Print Surf clanping pressures are in Kg_f/ cm^2

TABLE VI

SUMMARY OF THE STANDARD DEVAITIONS FOR THE COLLECETED DATA

DRYING RATE	K&N INK	OPACITY	BRIGHTNESS	POROSITY	GLOSS	IGT PICK STRENGTH
0.3% SIZED BASE PAPER UNCALENDERED						
L	1.23	1.90	0.23	3.79	0.75	---
M	1.37	0.92	0.21	2.33	0.59	---
H	1.83	1.30	0.16	2.71	0.36	---
0.3% SIZED BASE PAPER CALENDERED						
L	0.73	0.92	0.37	1.71	1.80	4.40
M	0.70	0.82	0.34	14.10	2.20	4.50
H	1.25	1.10	0.38	1.05	2.30	4.40
0.5% SIZED BASE PAPER UNCLAENDERED						
L	0.90	1.00	0.75	3.02	0.55	---
M	1.40	0.86	0.34	2.10	0.65	---
H	2.00	1.00	0.31	2.50	0.56	---
0.5% SIZED BASE PAPER CALENDERED						
L	0.74	1.00	0.34	1.50	1.20	3.00
M	0.68	0.91	0.27	1.10	1.80	3.20
H	1.63	1.20	0.30	0.82	1.40	4.20

FIGURE THREE: THE WATER REMOVAL RATE VS. OPACITY FOR THE 0.3% SIZED BASESTOCK



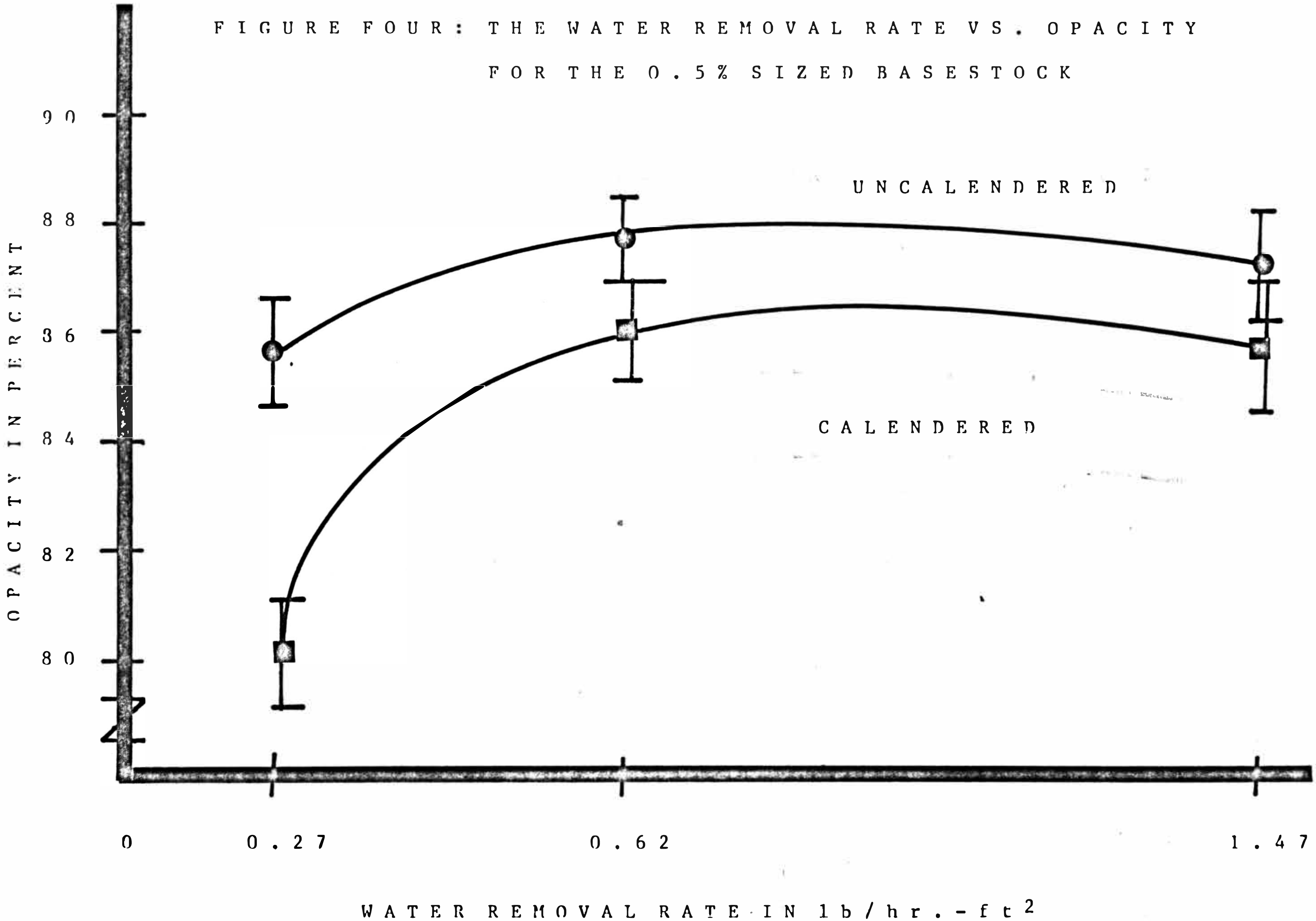
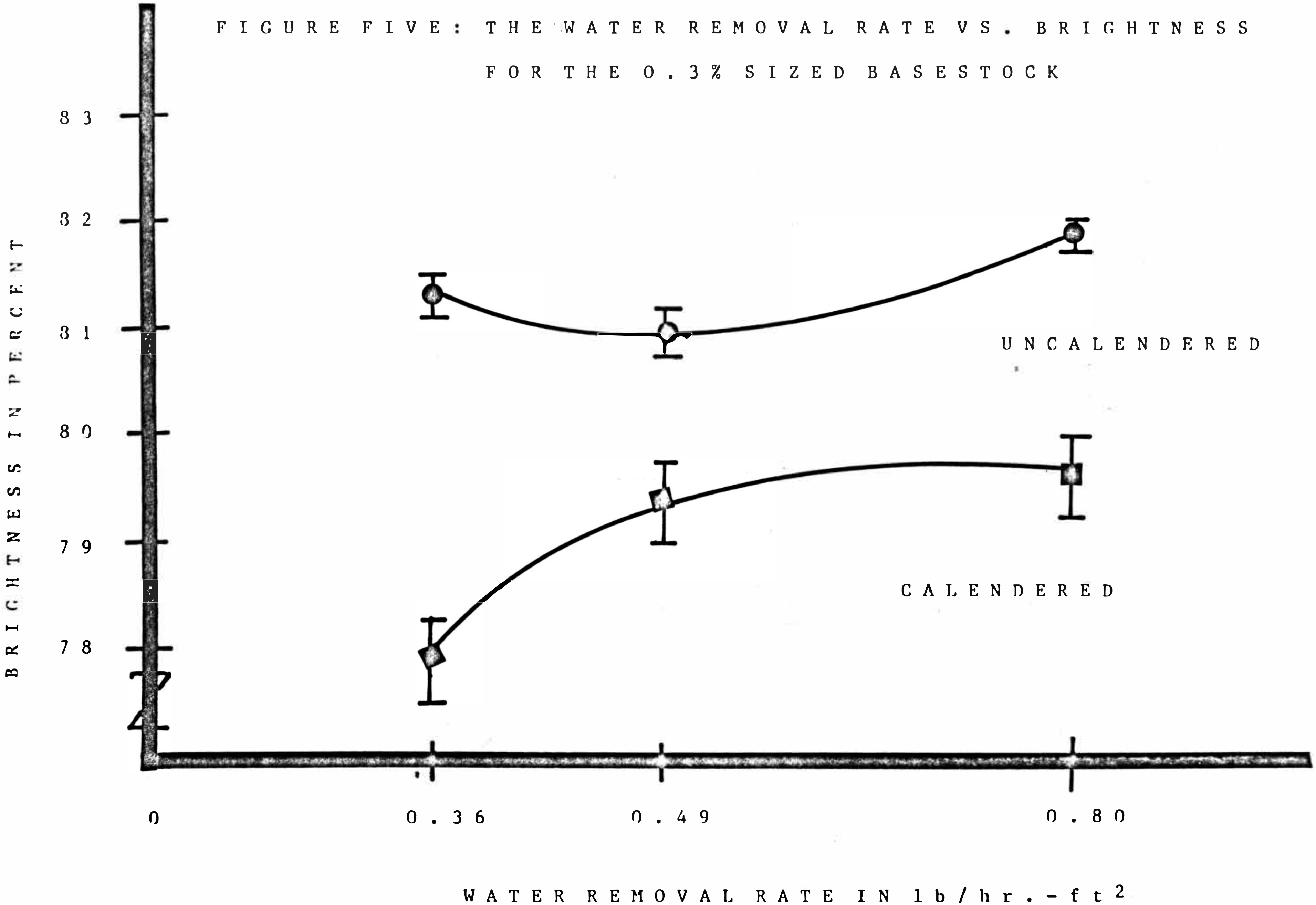


FIGURE FOUR: THE WATER REMOVAL RATE VS. OPACITY
FOR THE 0.5% SIZED BASESTOCK
UNCALENDERED
CALENDERED
OPACITY IN PERCENT
90
88
86
84
82
80
0
0.27
0.62
1.47
WATER REMOVAL RATE IN lb/hr.-ft2

FIGURE FIVE: THE WATER REMOVAL RATE VS. BRIGHTNESS FOR THE 0.3% SIZED BASESTOCK



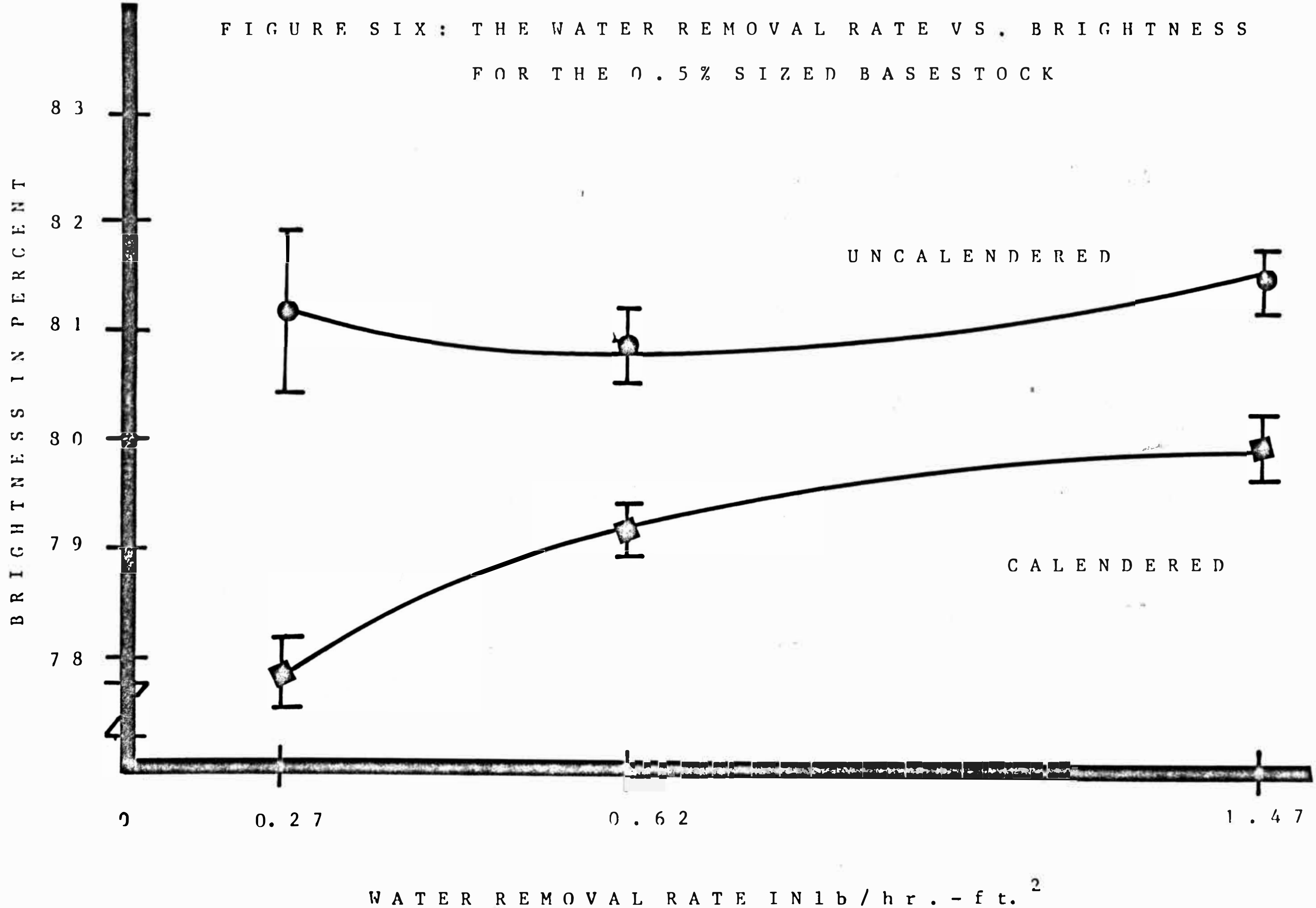


FIGURE SIX: THE WATER REMOVAL RATE VS. BRIGHTNESS
FOR THE 0.5% SIZED BASESTOCK
BRIGHTNESS IN PERCENT
83
82
81
80
79
78
UNCALENDERED
CALENDERED
0
0.27
0.62
1.47
WATER REMOVAL RATE IN lb/hr.-ft.2

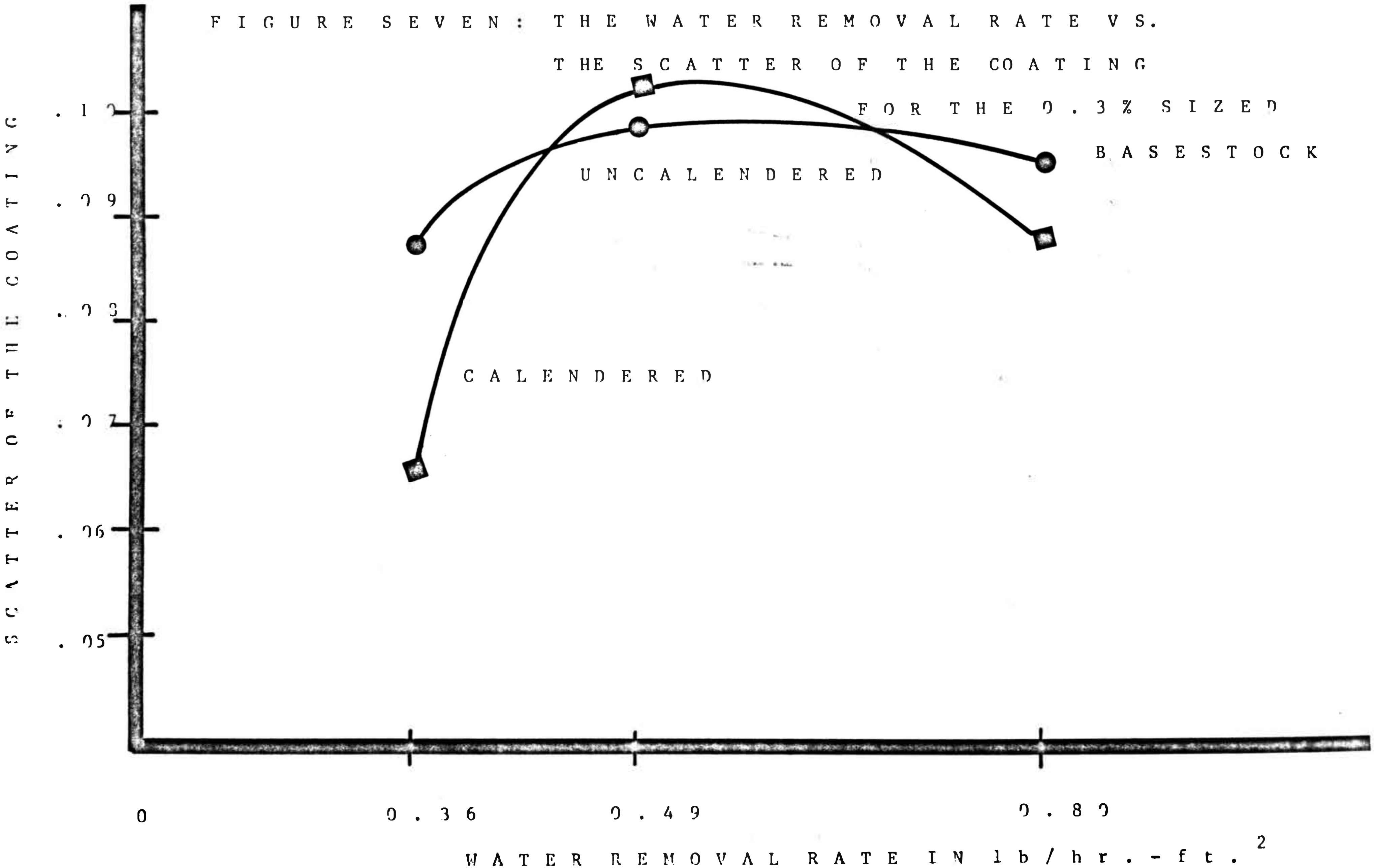


FIGURE SEVEN: THE WATER REMOVAL RATE VS. THE SCATTER OF THE COATING FOR THE 0.3% SIZED BASESTOCK

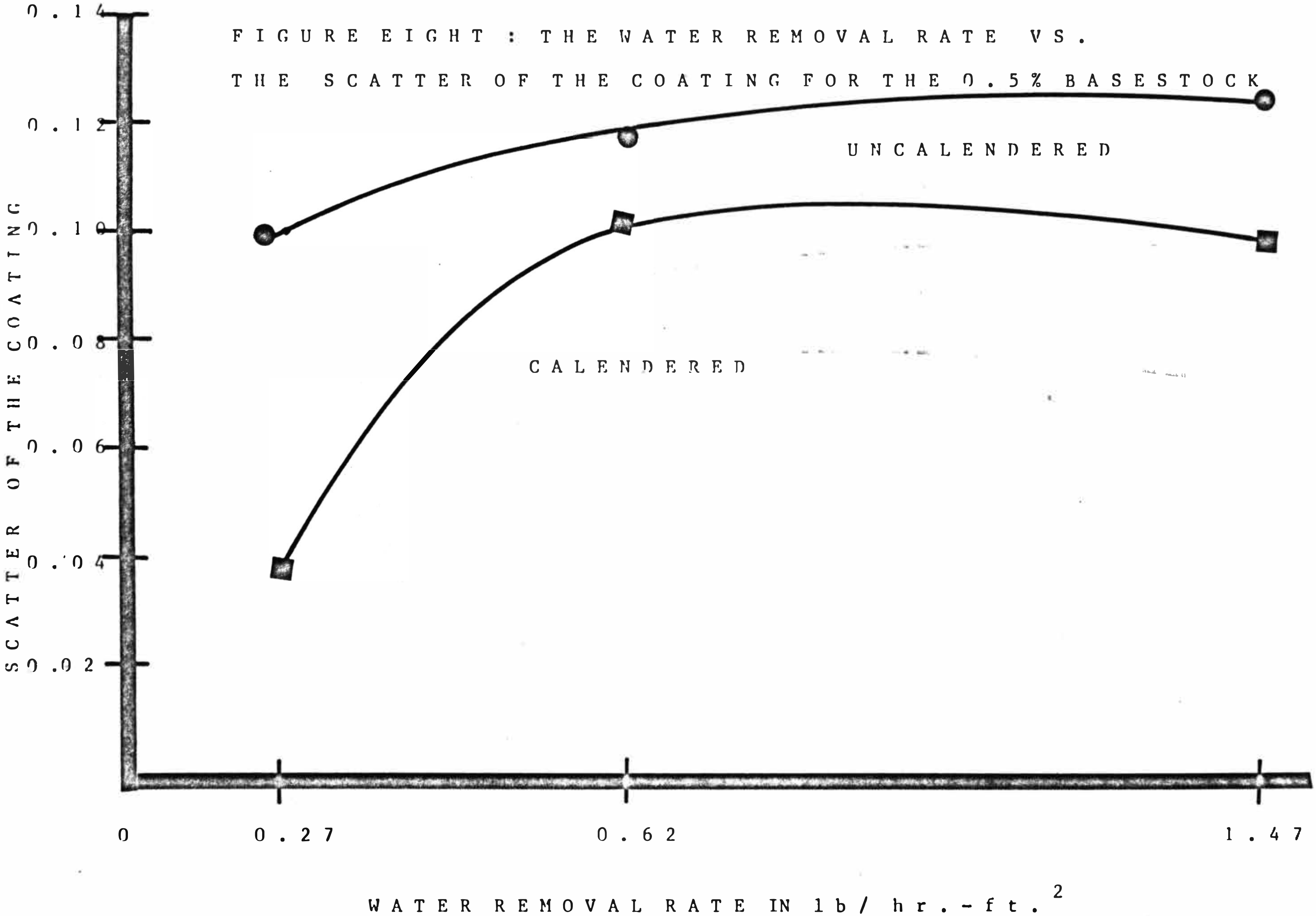


FIGURE EIGHT: THE WATER REMOVAL RATE VS. THE SCATTER OF THE COATING FOR THE 0.5% BASESTOCK

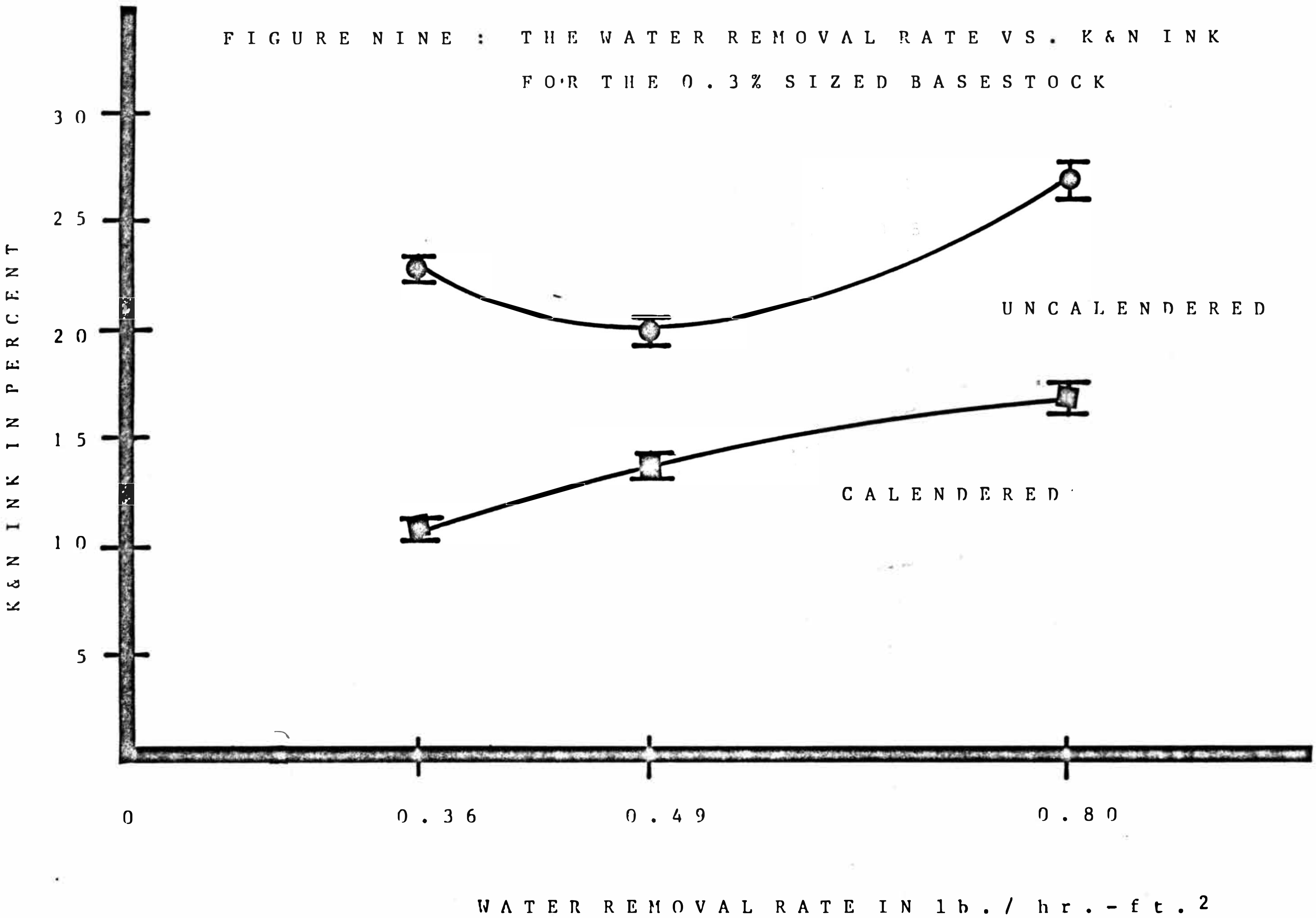


FIGURE NINE : THE WATER REMOVAL RATE VS. K&N INK
FOR THE 0.3% SIZED BASESTOCK
K&N INK IN PERCENT
30
25
20
15
10
5
UNCALENDERED
CALENDERED
0
0.36
0.49
0.80
WATER REMOVAL RATE IN lb./hr.-ft.2

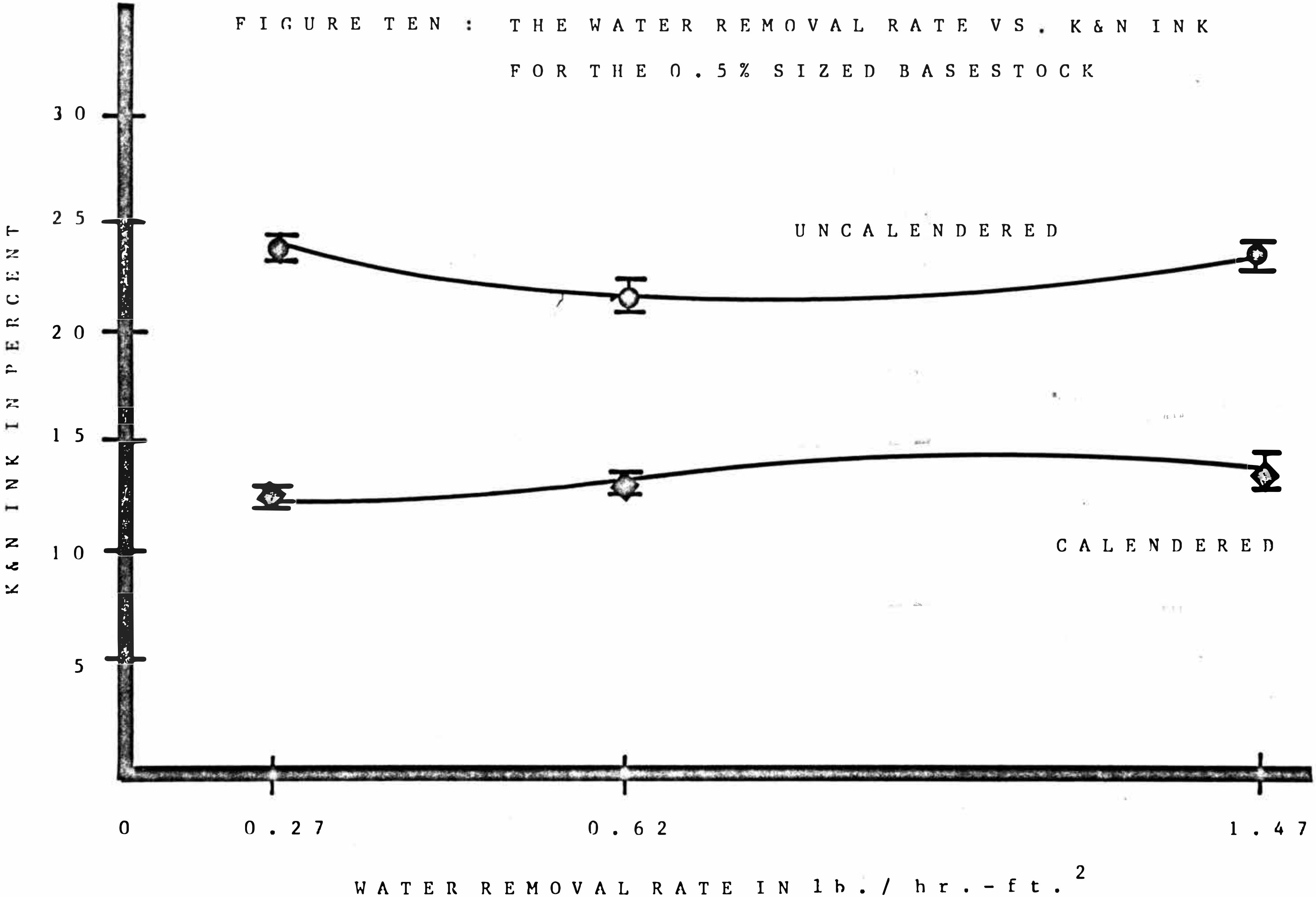


FIGURE TEN: THE WATER REMOVAL RATE VS. K&N INK
FOR THE 0.5% SIZED BASESTOCK
K&N INK IN PERCENT
30
25
20
15
10
5
0
UNCALENDERED
CALENDERED
0.27
0.62
1.47
WATER REMOVAL RATE IN lb./hr.-ft.^{2}

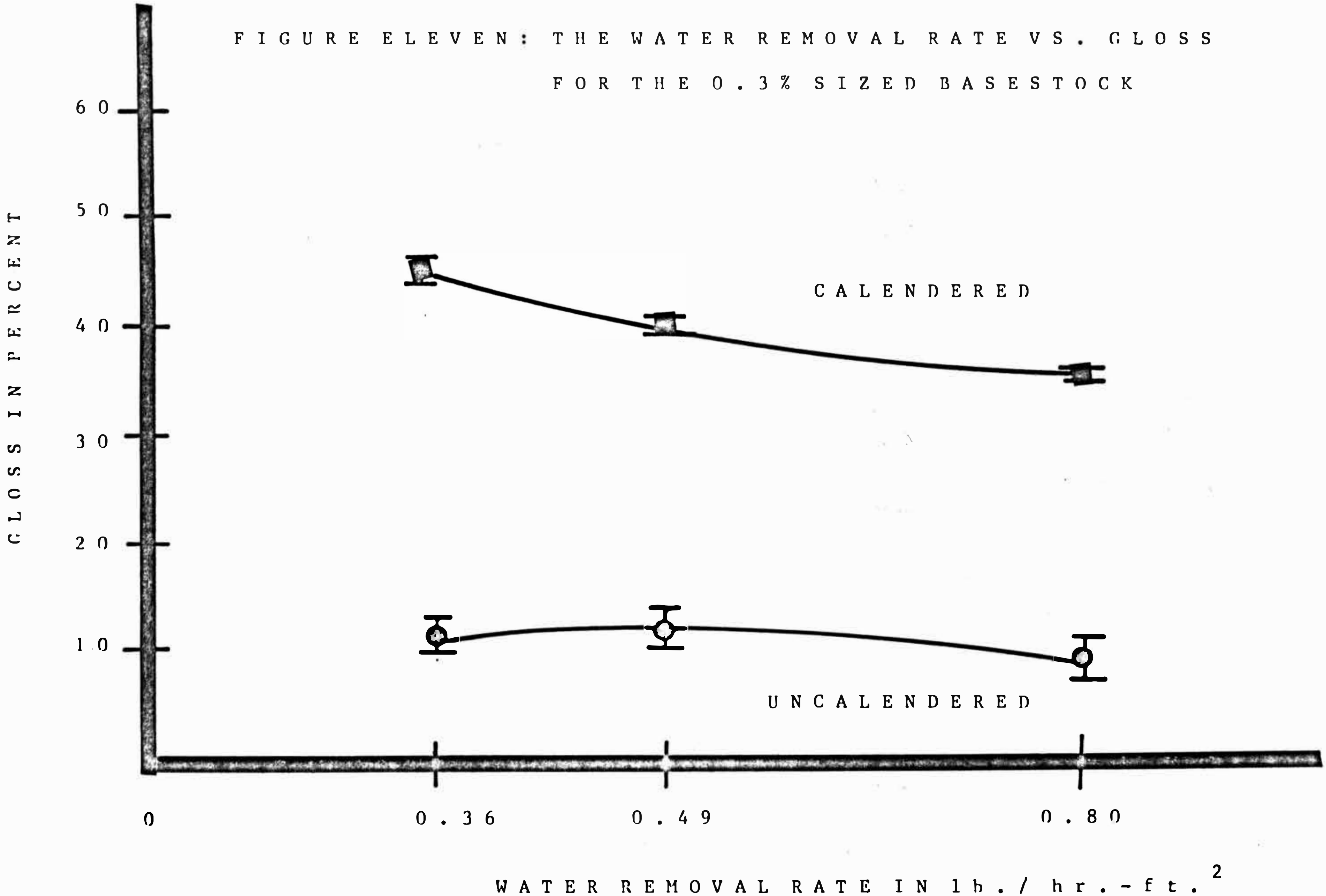


FIGURE ELEVEN: THE WATER REMOVAL RATE VS. GLOSS
FOR THE 0.3% SIZED BASESTOCK
GLOSS IN PERCENT
60
50
40
30
20
10
CALENDERED
UNCALENDERED
0
0.36
0.49
0.80
WATER REMOVAL RATE IN lb./hr.-ft.2

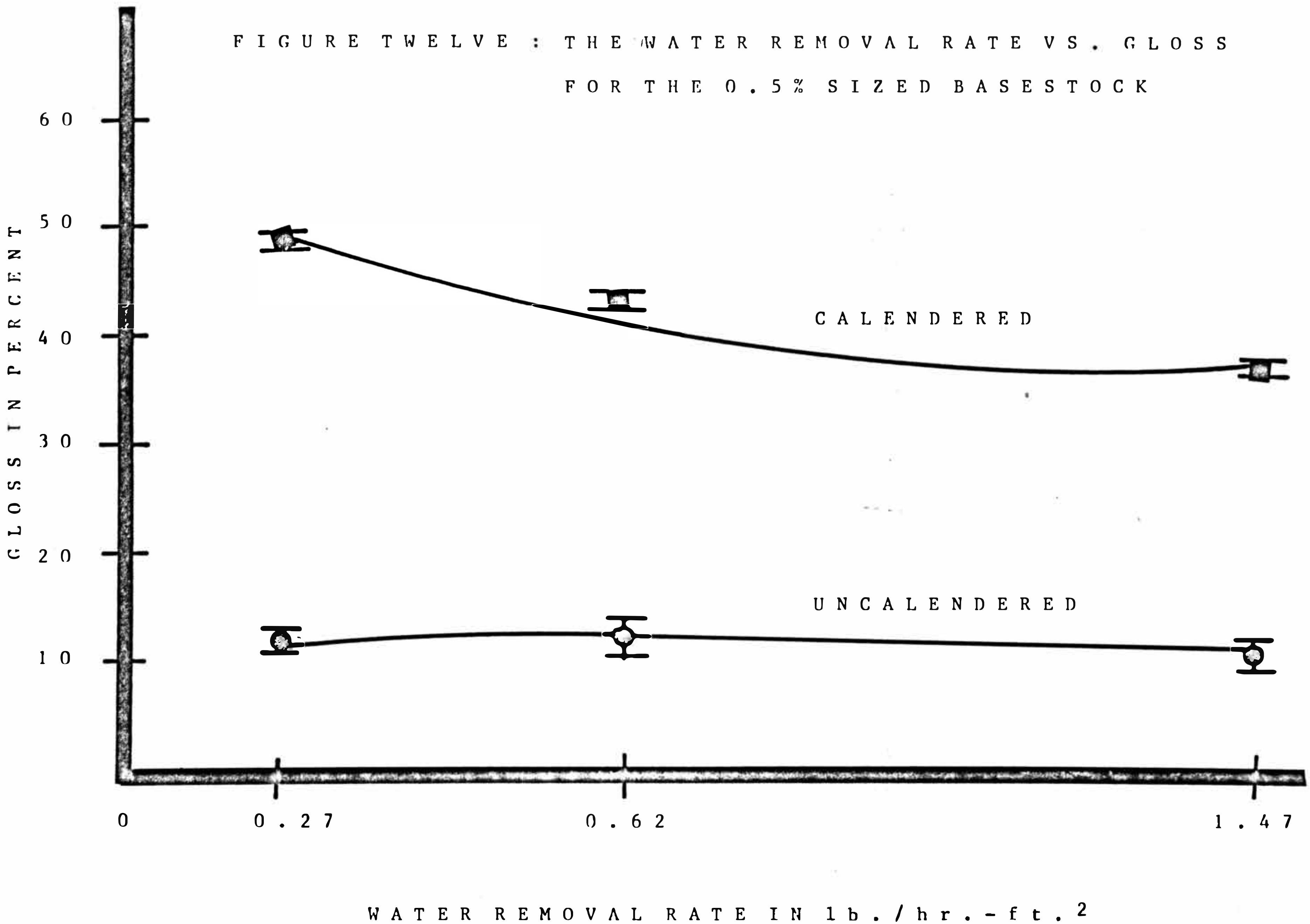
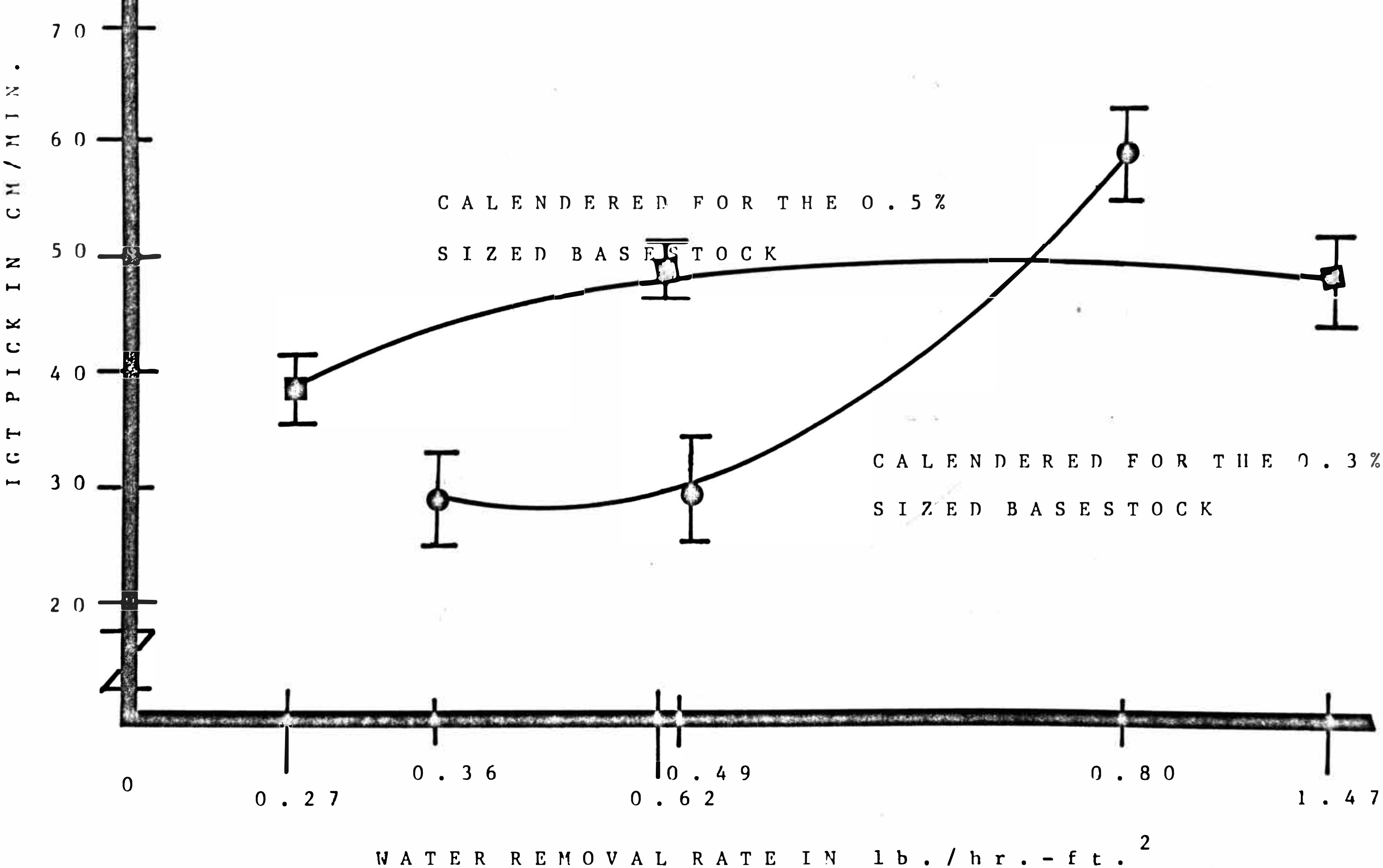


FIGURE TWELVE : THE WATER REMOVAL RATE VS. GLOSS
FOR THE 0.5% SIZED BASESTOCK
GLOSS IN PERCENT
60
50
40
30
20
10
CALENDERED
UNCALENDERED
0
0.27
0.62
1.47
WATER REMOVAL RATE IN lb./hr.-ft.2

FIGURE THIRTEEN : THE WATER REMOVAL RATE VS. IGT PICK



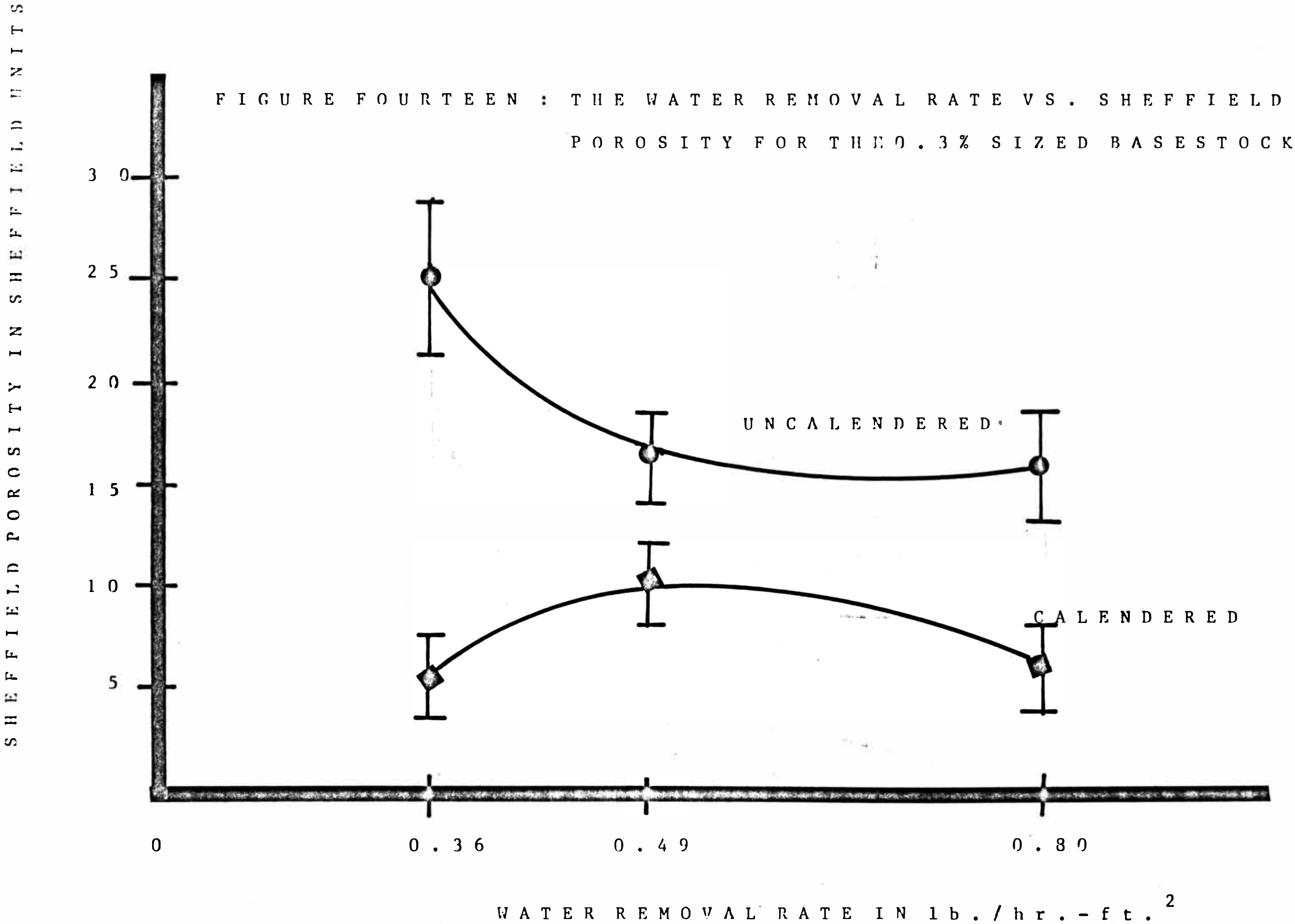


FIGURE FOURTEEN : THE WATER REMOVAL RATE VS. SHEFFIELD POROSITY FOR THE 0.3% SIZED BASESTOCK
SHEFFIELD POROSITY IN SHEFFIELD UNITS
30
25
20
15
10
5
UNCALENDERED
CALENDERED
0
0.36
0.49
0.80
WATER REMOVAL RATE IN lb./hr.-ft.²

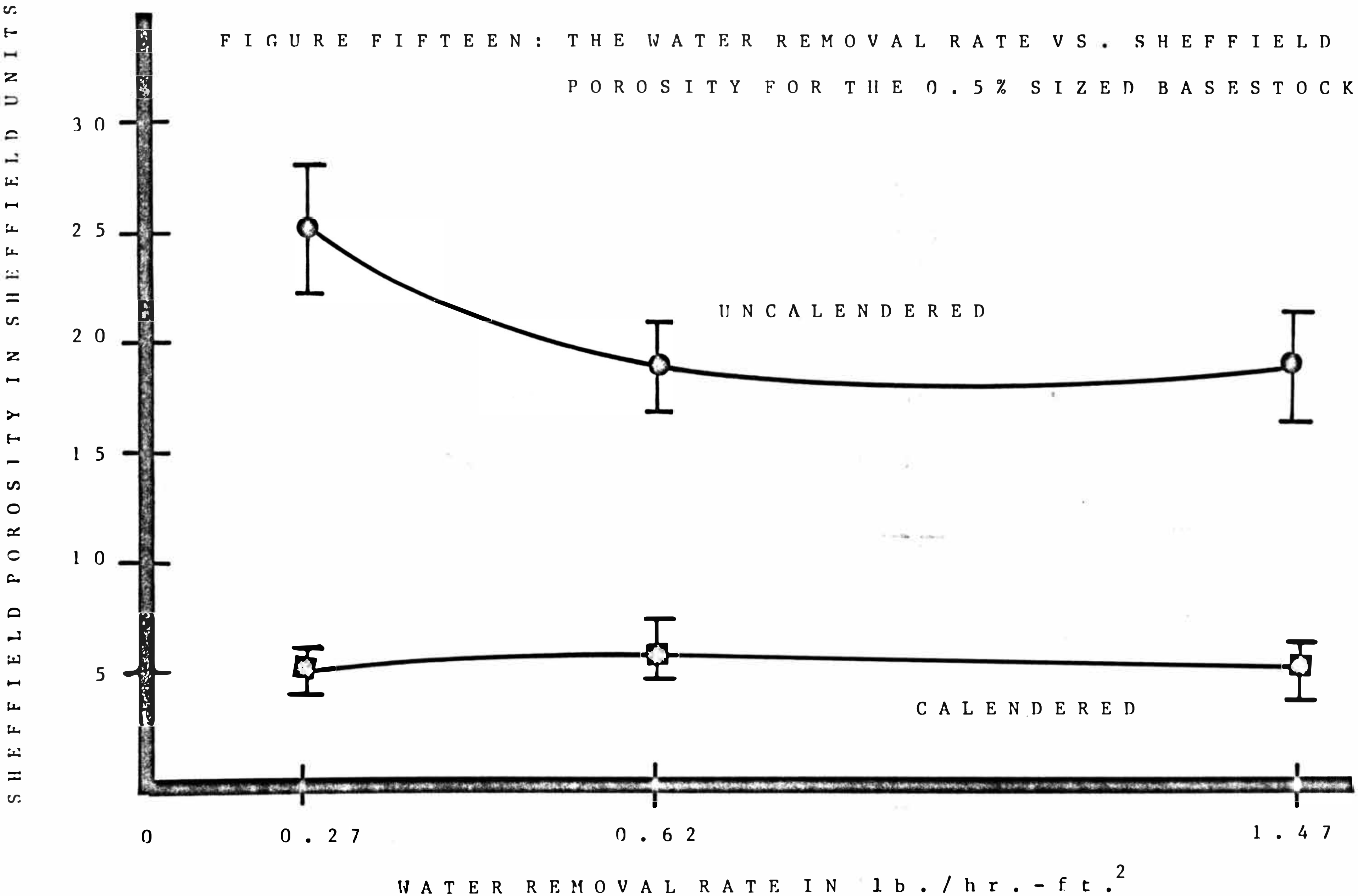
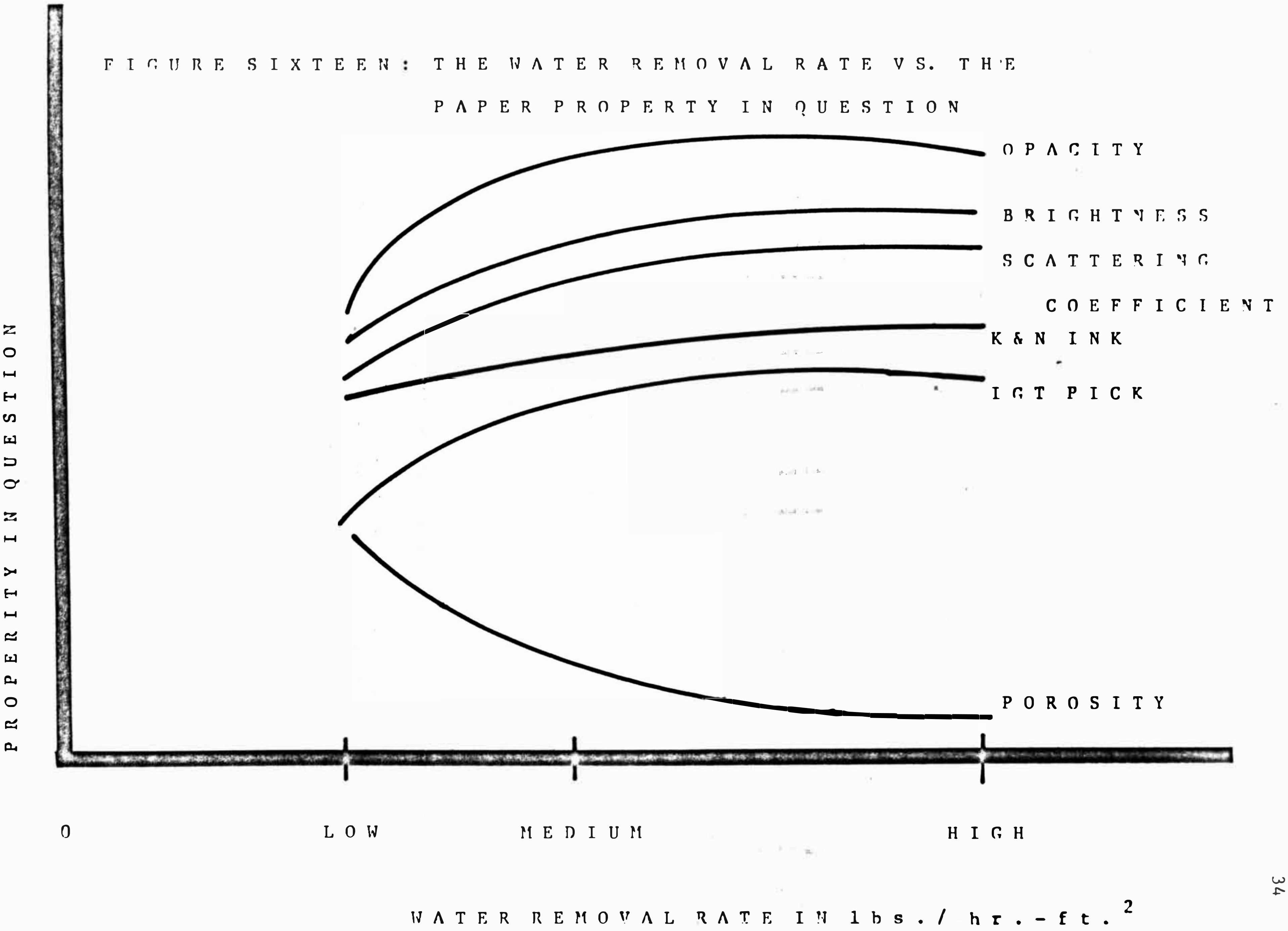


FIGURE FIFTEEN: THE WATER REMOVAL RATE VS. SHEFFIELD POROSITY FOR THE 0.5% SIZED BASESTOCK

FIGURE SIXTEEN: THE WATER REMOVAL RATE VS. THE PAPER PROPERTY IN QUESTION



PRESENTATION AND DISCUSSION OF RESULTS

The basic trends of the effect of drying rate on all coated paper properties is shown in the summary graph, Figure 16. By using this figure, one can see the following: the optical properties all increase as the drying rate increases. The gloss and porosity of the coating falls off with an increase in the drying rate. The pick strength of the coating increases as the rate of drying is increased.

Supercalendering lowered all coated paper properties. A probable cause for this is that the calendering equalized the pore structure differences by the force applied.

A probable cause for the increase in the optical properties as the drying rate increased is that because more binder remained in the coating it was more subject to cracking due to shrinkage during drying. The cracking of the binder would create more surfaces in the coating layer, thus increasing the scattering coefficient of the coating which will increase the optical properties. The cracking of the binder also could explain the reduction in gloss as the drying rate was increased. The more surfaces in the coating would cause less light to be specularly reflected and thus, a lower gloss.

Dealing with the differences in the IGT trends between the different base papers the following could be one explanation: The 0.5% sized paper seems to have enough sizing to stop the migration of the binder into the sheet, thus the effect of the drying rate is minimal. As for the 0.3% sized paper, the binder might be migrating into the base sheet in the lower drying rates, but at the higher rates of drying less binder migration into the paper occurs, thus producing a coating of higher pick strength.

The porosity of the coating decreased as the rate of drying was increased, thus a possible explanation would be less loss of binder to the base sheet as the rate of dryng was increased. This would produce a layer of less continuous pores thus, lowering the porosity of the coating.

CONCLUSIONS

The following conclusions may be drawn for this work:

1. An IR dryer may dry the coating in such a way to crack the starch binder, thus producing more surfaces in the coating layer. These new surfaces increase the optical properties of the coating, but reduce the gloss.

2. The increase in drying rate reduced the porosity of the coating.

3. The increase in the drying rate had little effect on the smoothness of the coating.

4. In the lower-sized papers, as the drying rate was increased it had more effect on the migration of the binder into the sheet than did the sizing level of the sheet.

This work confirms the work of Hultman (11). He also found the pick strength increased and the gloss of the coating slightly decreased as the rate of drying was increased.

RECOMMENDATIONS FOR FURTHER RESEARCH

These recommendations for further research may be offered:

1. To use a hot air blower to dry the coated sheet at an increased rate to more closely simulate rates of 4 - 10 lbs./hr./-ft.^{2}

2. To increase the speed of the coater and to increase the drying ability to achieve higher water removal rates.

3. To study the mechanisms of drying effects on one or more properties of coated papers.

APPENDIX ONE

Basic equations for the calculation of the drying rate of coated papers.(9)

Stepwise calculations for dryer study

Water in basestock [lb/(hr)(ft)] = [(coater speed)(basestock a.d. wt) (% moisture in basestock)(60)] / [(3300)(100)]	(1)
Water in coating applied [lb/(hr)(ft)] = [(coater speed)(o.d. coating wt) (60) (100) / (3300) (% coating solids)] − [(coater speed) (o.d. coating wt) (60) / (3300)]	(2)
Water in sheet exiting dryer [lb/(hr)(ft)] = [(coater speed)(coated sheet o.d. basis wt)(% moisture out of dryer)(60)] / [(100 − % moisture out of dryer)(3300)]	(3)
Water removed by dryer [lb/(hr)(ft)] = Eq. 1 + Eq. 2 − Eq. 3	(4)
Water removal rate [lb/(hr)(ft^2)] = (water removed by dryer)/(drying length)	(5)
Sensible heat transferred to coating [Btu/(hr)(ft)] = (0.25) [o.d. coating wt applied/(hr)(ft)](ΔT_{web})	(6)
Sensible heat transferred to sheet [Btu/(hr)(ft)] = (0.35) [o.d. basestock wt/(hr)(ft)](ΔT_{web})	(7)
Sensible heat transferred to water in sheet [Btu/(hr)(ft)] = (1.0)(water in basestock)(ΔT_{web})	(8)
Sensible heat transferred to water in coating [Btu/(hr)(ft)] = (1.0)(water in coating applied)(ΔT_{web})	(9)
Latent heat transferred [Btu/(hr)(ft)] = (water removed by dryer)(heat of vaporization at web exiting temperature)	(10)
Total heat load transferred [Btu/(hr)(ft)] = Eq. 6 + Eq. 7 + Eq. 8 + Eq. 9 + Eq. 10	(11)
Overall heat-transfer coefficient [Btu/(hr)(ft^2)(F°)] = (total heat load transferred) / (heat transfer area)(ΔT_{lm})	(12)

ΔT_{web} = (web temperature exiting dryer) − (web temperature into dryer)

ΔT_1 = (low-velocity supply-air temperature) − (web temperature into dryer)

ΔT_2 = (medium-velocity supply-air temperature) − (web exit temperature)

ΔT_{lm} = $(\Delta T_1 - \Delta T_2) / \ln(\Delta T_1/\Delta T_2)$
= logarithmic mean temperature

SAMPLE CALCULATION OF THE DRYING RATE FOR THE LOW RATE OF 0.3% SIZED BASE PAPER

$$\text{Water in Basestock (lb./hr.-ft)} = \frac{(\text{Coater Speed})\ (\text{Basestock A.D. Weight})\ (\%\ \text{Moisture})\ (60)}{(3{,}300)\ (100)}$$

$$= \frac{(4.31)\ (45.88)\ (5.17)\ (60)}{(3{,}300)\ (100)}$$

Eq. 1. Water in Basestock is 0.1859 lb./hr.-ft.

$$\text{Water in Coating Applied (lb./hr.-ft.)} = ([\text{Coater Speed}]\ [\text{O.D. Coating Wt.}]\ [6000]\ /\ 3000\ [\%\ \text{Solids}])$$
$$\text{minus } ([\text{Coater Speed}]\ [\text{O.D. Coating Wt.}]\ [60]\ /\ 3{,}300\ )$$

$$= ([4.31]\ [9.62]\ [6{,}00]\ /\ [3{,}000]\ [44.25])$$
$$\text{minus } ([4.31]\ [9.62]\ [60]\ /\ 3{,}000\ )$$

Eq. 2. Water in coating applied is 0.9498 lb./hr.-ft.

$$\text{Water Exiting Dryer in Sheet} = \frac{(\text{Coater Speed})\ (\text{Coated Sheet O.D. Wt.})\ (\%\ \text{Moisture})\ 60}{(100 - \%\ \text{Moisture Out})\ (3{,}300)}$$

$$= \frac{(4.31)\ (53.12)\ (12.37)\ (60)}{(100 - 12.37)\ (3{,}300)}$$

Eq. 3. Water exiting dryer in sheet in 0.6097 lb./hr.-ft.

Water Removed By Dryer (lb./hr.-ft.) = Eq. 1 + Eq. 2 − Eq. 3 = 0.1859 + 0.9498 − .6097

Eq. 4. Water removed by dryer is 0.526 lb./hr.-ft.

Water Removal Rate (lb./hr.-ft.)

Eq. 4 / Dryer Length = 0.526/1.507 = 0.349 lb./hr.-ft.^{2}

APPENDIX II

PROCEDURES FOR PARKER-PRINT SURF SMOOTHNESS, IGT PICK STRENGTH, SCATTERING COEFFICIENT, AND K & N INK ABSORPTION

Parker-Print Surf Smoothness

This test was done following the operation manual for the Parker-Print Surf model 750 at the following conditions:

1. Using 0.62 metres Wg air pressure,
2. Using the cork backing, and
3. Taking readings using 10 and 20 kg_f/cm^2 for the clamping pressures.

IGT Pick Strength

This test was done following the operation manual at the following conditions:

1. Using an off-set blanket as the backing pad,
2. Using the Westvaco application roll
3. Using number five tack ink, and
4. Using an operation speed 0.5 m/sec.

Scattering Coefficient

The scattering coefficient was calculated using the following data:

1. The base paper opacity and brightness, and
2. The coated stock opacity, brightness, and coat weight.

The calculations for the scattering coefficient were carried out by using the following computer program bsed on the Clark-Ramsey Method (14).

K & N Ink Absorption

This test was carried out my mesuring the brightness of the sheet, then applying a layer of K & N ink to the sheet where the brightness value was taken. After two minutes, the ink layer was wiped off the sheet and another brightness value was taken off the inked surface. The calculation of K & N ink absorption is as follows:

$$\% \text{ K \& N Ink Absorption} = \frac{\text{Uninked Brightness} - \text{Inked Brightness}}{\text{Uninked Brightness}} \times 100$$

CLARK 16:11 14-APR-84

```
1 PRINT"CLARK-RAMSAY TAPPI 48(11) NOV. 1965 PP 609-612"
2 PRINT"PROGRAM TO DETERMINE THE SCATTERING COEFFFICIENT OF THE"
3 PRINT"COATING FOR A C1S SHEET GIVEN THE BRIGHTNESS AND OPACITY"
4 PRINT"OF THE RAW STOCK AND THE RIGHTNESS, OPACITY, AND COAT"
5 PRINT"WEIGHT OF THE C1S SHEET."
99   PRINT"ALL NUMBERS ENTERED MUST BE SEPERATED BY COMMAS."
100  PRINT"ENTER RAW STOCK OPACITY AND BRIGHTNESS (USE DECIMALS)."
110  INPUT C,R
120  PRINT"ENTER THE NUMBER OF DATA SETS FOR THIS RAW STOCK."
130  INPUT J
140  PRINT"ENTER THE COATED SHEET OPACITY, BRIGHTNESS, AND COAT WEIGHT."
150  FOR I=1 TO J
160  INPUT C(I),R(I),X(I)
170  NEXT I
200  LET A=0.89/C
210  LET B=1-0.89/R-0.89*R-1/C
215  REM D=ROP
220  LET D=(-B+SQR(B^2-4*A*0.89))/(2*A)
230  IF D<0 GO TO 250
240  IF D<1 GO TO 260
250  LET D=(-B-SQR(B^2-4*A*0.89))/(2*A)
255  REM T=TP
260  LET T=SQR(1-D*(1/R+R)+D^2)
300            FOR I=1 TO J
310                LET A(I)=0.89/C(I)
320                LET B(I)=1-0.89/R(I)-0.89*R(I)-1/C(I)
325                REM D(I)=ROD
330           LET D(I)=(-B(I)+SQR(B(I)^2-4*A(I)*0.89))/(2*A(I))
340                    IF D(I)<0 GO TO 360
350                   IF D(I)<1 GO TO 370
360                LET D(I)=(-B(I)-SQR(B(I)^2-4*A(I)*0.89))/(2*A(I))
365                REM T(I)=TD
```

```
372   REM
399   REM CALCULATION OF ROC
400               LET H=T(I)/T
410               LET Y=H*D
420               LET Z=1-Y^2
430               LET E=Y/Z
440             LET F=D(I)/Z
450               LET G=E*H
460               LET O(I)=F-G
490   REM
499   REM CALCULATION OF TC
500               LET Q=H/Z
510               LET U=D(I)*E
520               LET V(I)=Q-U
590   REM
595   REM
600               LET E(I)=(V(I)^2-1-O(I)^2)/(O(I))
610               LET Y(I)=SQR(E(I)^2-4)
620               LET Z(I)=(-E(I)+Y(I))/2
621                   IF Z(I)<0 GO TO 623
622                   IF Z(I)<1 GO TO 630
623               LET Z(I)=(-E(I)-Y(I))/2
630               LET P(I)=LN((1-O(I)*Z(I))/(1-O(I)/Z(I)))
640       LET P(I)= P(I)/((1-Z(I)^2)/Z(I))
650               LET S(I)=P(I)/X(I)
660           NEXT I
665   PRINT
666   PRINT
700   PRINT"VALUES FOR COATING CALCULATED BY THE CLARK METHOD."
701   PRINT
705   PRINT"NO.","COAT WT.","RO","RI","S"
706   PRINT
710           FOR I=1 TO J
720          PRINT I,X(I),O(I),Z(I),S(I)
730           NEXT I
735   PRINT
740   PRINT
800   PRINT"DO YOU WISH TO CONTINUE?"
805   PRINT"IF YES TYPE 1, IF NO TYPE 2."
810   INPUT M
820   IF M=1 GO TO 99
```

```
Ready
RUN

CLARK           16:13          14-APR-84


CLARK-RAMSAY TAPPI 48(11) NOV. 1965 PP 609-612
PROGRAM TO DETERMINE THE SCATTERING COEFFFICIENT OF THE
COATING FOR A C1S SHEET GIVEN THE BRIGHTNESS AND OPACITY
OF THE RAW STOCK AND THE RIGHTNESS, OPACITY, AND COAT
WEIGHT OF THE C1S SHEET.
ALL NUMBERS ENTERED MUST BE SEPERATED BY COMMAS.
ENTER RAW STOCK OPACITY AND BRIGHTNESS (USE DECIMALS).
 ?.791,.854
ENTER THE NUMBER OF DATA SETS FOR THIS RAW STOCK.
 ?1
ENTER THE COATED SHEET OPACITY, BRIGHTNESS, AND COAT WEIGHT.
 ?.862,.813,9.62


VALUES FOR COATING CALCULATED BY THE CLARK METHOD.

NO.            COAT WT.       RO             RI             S

 1              9.62           0.439337       0.773824       8.48662E-2


DO YOU WISH TO CONTINUE?
IF YES TYPE 1, IF NO TYPE 2.
 ?2
```

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